Status of the Glacier Research in the HKH region

By
Dr. S. I. Hasnain
School of Environmental Sciences
Jawahar Lal Nehru University
INDIA

The climate of Himalaya is essentially dominated by the south-west monsoon which provides most of the precipitation in the eastern and central regions during the summer months. The westerlies which predominate during the rest of the year bring snow and rain in the winter and spring period, most significantly in the western part of the mountain system. Himalayan mountain system block the northward advancement of monsoon causing widespread intense precipitation on the southern side of the Himalaya, making the Tibetan Plateau and northern rain shadow areas as one of the driest region in the world. This indicate that the most important water resource in the western and central Indian Himalaya comes from the monsoonal rainfall, snow and glacier ice-melt. The quantitative assessment of their contribution to the river flow has been limited since the melting processes is very complicated and not well understood. Therefore it is of great importance to understand the hydrological processes in the HKH region.

About 75% of the runoff in three major river systems; the Brahmaputra, Ganga and Indus occurs between June and September, in response to the snow and glacier ice-melt (Collins and Hasnain, 1995).The water supply to these rivers from glaciers during the melting and lean season is more stable and predictable than that from rainfall; glaciers behave like natural reservoirs. IPCC (1996) predicted that up to a quarter of the present mountain glacier mass could disappear by 2050 due to global warming. A decrease of glacier mass of this magnitude presents a serious water resources problem for the millions of peoples living within the HKH region and in the adjoining plains.

The relatively young age of the Himalayan mountains with their large and active glaciers, high seismisity, steep valleys with frequent avalanching and intense monsoonal rainfall, support high erosion rates (Hasnain and Chauhan, 1993). Himalayan glaciers produce a large amount of rock debris and have large lateral and terminal moraines compared with glaciers in many other areas. As a result moraine-dammed lakes commonly form in front of retreating glaciers. These are unstable and a slight disturbance by seismisity or heavy rainfall can easily result in an abrupt release of stored water and rock debris (Yamada,1993). Furthermore, high velocity, erosive glaciers driven by high accumulation rates, steep topographic gradients, and high rates of ablation yield is causing high concentrations of sediment in their melt-waters. Such glaciers are thought to be important active agents of erosion and sediment transport in regional denudation system (Gardner, 1986).

The termini altitudes of the glaciers are low in the western Himalaya as they are located at higher latitudes than those in central and eastern Himalaya. Distinct differences can also be seen between the termini altitudes on the south slope and those on the north slope: low altitudes of the termini on the south slope of the Himalaya reflect the higher accumulation due to the Indian monsoon. Ageta and Higuchi (1984) named these glaciers which have more accumulation in summer than winter, as the 'summer-accumulation type', and differentiated them from the 'winter-accumulation type' glaciers well known in Europe and north America. On the summer-accumulation type glaciers, accumulation and ablation mainly occur simultaneously in summer. Under such conditions, summer snowfall sometimes changes to rain under warm air temperature condition, and also new snow cover melts away quickly under such condition. Consequently, summer air temperature in the Himalaya is an important factor which controls ablation through albedo variation at the glacier surface.

Thus, summer air temperature is one of the important factors for controlling both accumulation and ablation. In the summer-accumulation type of glaciers, accumulation conditions strongly affect ablation since both occur simultaneously in summer. Snowfall is concentrated in summer when insolation is strong and the ablation reducing effect is significant because of high albedo of new snow. In addition, extensive cloud cover, which produces summer snowfall, reduces insolation in the ablation season.

Glaciers in the Indian Himalaya covers an area of 38,039 km^2, broadly divided into three river basins-- Indus, Ganga and Brahmaputra. The Indus basin has the largest number of glaciers 3,538, followed by the Ganga basin 1,020 and Brahmaputra 662. The glaciers are situated in five states -- Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, Sikkim, and Arunachal Pradesh. Kashmir has the largest concentration with 3,136 glaciers covering 32,000 km^2, nearly 13 % of the State's territory. The average area of a glacier in the state is 10.24 km^2. Nine per cent of U.P. Himalaya is covered by 917 glaciers having an area of 3,550 km^2. Sikkim has 450 glaciers spread over 912 km^2. The average size is 1.59 km^2. Arunachal Pradesh has 162 glaciers covering 228 km^2. The average size is 1.41 km^2.

It has been estimated by various researchers that about 17 % of the Himalaya and 37 % of Karakoram are covered by glacier ice. The principal glaciers of the Himalaya are Siachen 72 km, Gangotri 26 km, Zemu 26 km, Milam 19 km, and Kedarnath 14.5 km. Vohra (1996) stated that the glaciers are found in all those areas which attain or exceed the heights necessary for glacier generation. The major clusters of glaciers occur in and around the following ten Himalayan peaks and massifs: Nanga Parbat, the Nanda Devi group, the Dhaulagiri massif, the Everst-Makalu group, the Kanchenjunga, the Kula Kangri area, and Namche Barwa. Similarly the K-2 region in the Karakoram mountains, Pakistan is highly glaciated and supports several of the largest glaciers.

Glacier mass balance is an important glaciological parameter and is intimately related to climate. The mass balance is calculated as the sum of the accumulation(amount of snow and ice added tyo the glacier: taken as positive) and ablation (amount of snow and ice lost from a glacier: taken as negative). Accumulation comes from solid precipitation and from sublimation of water vapour, both of which are input directly from the atmosphere to the glacier surface. There can be indirect accumulation as in the HKH region from extensive avalanching. Accumulation and ablation have annual cycles dependent on seasonal climates, and the cumulative result of annual mass balance cause glacier variations. Unfortunately none of the glacier in the HKH region has been monitored for long term mass balance observation. In the Nepal Himalaya,however, many long term observations on mass balance were made by (Ageta et. al. 1980; Ageta, 1983) on glaciers in east Nepal. They observed on the basis of experimental results on small glacier that the altitude difference between the equilibrium lines for annual balance and balance in summer is less than 50 m due to little accumulation in winter, and the rising equilibrium line is more toward the lower temperature altitudes in the lower precipitation area due to less sensitivity of mass balance to change of air temperature in the colder conditions at the higher altitudes. On the other hand, large glaciers which have large accumulation basins with peaks above 6000 m, precipitation does not change to rain, since it is cold enough to keep snowfall. Therefore, the variations of large glaciers does not depend as strongly on air temperature as that of small glaciers. Inoue (1977) made estimation on mass balance of Khumbu glacier in Mt. Sagarmatha (Everest) region. He showed that the mass supply from the surroundings wide walls by avalanches and snow drifting is more important for the equilibrium of mass balance for the whole area of the glacier; such mass supply was estimated to be nearly three times of direct snowfall onto the glacier.

A common characteristic of glaciers in the Nepal Himalaya is that the annual accumulation is provided mainly in summer by the Indian monsoon. The monsoon precipitation in summer (June- September) occupies about 80 % of annual precipitation. Ageta and Higuchi (1984) named these glaciers which have more accumulation in summer than winter, as the ' summer-accumulation type'', and differentiated them from the ' winter-accumulation type' glaciers. On the summer-accumulation type glaciers, accumulation and ablation occur simultaneously in summer. Therefore, summer air temperature is one of the important factors for controlling both of accumulation and ablation and balance during summer.

Effect of debris cover on the glacier melting has been analyzed by Rana et al. (1997). The studies conducted in Nepal by various Japanese researchers have indicated that glaciers are important as water resources, and the effect of suprglacial debris can not be neglected for exact evaluation of runoff from glacierized basins.

Ageta and Kadota (1997) predicted by the use of empirical mass balance model, that the equilibrium line altitude would exceed the present glacier top, if air temperature would rise 1.5 ^{0} C higher than that in the equilibrium state of mass balance for the whole glacier area, and in a case of 3 ^{0} C higher, annual balance at the glacier top would drop to -33 cm. If such conditions will continue, this glacier will finally disappear.

Glacier lake outburst studies have also been done very extensively in the eastern Nepal by (Yamada, 1998).

The total area covered by the glaciers in the China Himalaya is about 11000 km^2 (Shi and Li, 1980). Glacier termini of 100 glaciers has been studied by Li Jijun (1986). He found 47 glaciers were advancing and 53 retreating. The intensively investigated glaciers, such as Jiabula glacier, the Gechongba glacier, the glacier no. 9 in Dongrongbu and the Bula glacier etc. were all retreating. Most glaciers retreated from 10 m to several tens of meters. Most glaciers in the China Himalaya are retreating. For example, the Dasuopu glacier has been retreating since 1960s with an annual rate 4 m.

China is the only country in the Himalaya where Ice cores were extracted on glaciers. The ice cores were analyzed for climatology, chemistry and ice physics. Ice cores were recovered from the Dasuopu glacier in the Xixiabangma mountains located in the middle Himalaya. There is no visible dirty layer in the cores thus it can not be dated by counting annual dirty layers. There was no melt layer in the cores and this way glacial accumulation can be directly converted into precipitation. Interestingly the Chinsese study indicate that the precipitation record over the Dasuopu glacier is an Indian monsoon record. Their field observation indicates that the Indian Ocean air mass can climb over the Himalaya directly and reach the Dasopu glacier. Glacier lakes in China Himalaya are also extensively studies over the years. The middle Himalaya have many potentially dangerous lakes.

Geological survey of India has done the yearly specific balance for some glaciers in the Indian Himalaya. In his review paper Vohra (1996) mentioned that Gara glacier, sutlej catchment is perhaps the only glacier which has been studied for winter and summer period accumulation. The Garhwal and kumoun Himalaya have very similar hydrometeorological conditions as are prevalent in eastern Nepal and therefore it is important for the Indian glaciologists to study the summer balance as monsoon plays an important role in the accumulation processes.

The studies in hydrochemistry of meltwaters, sediment transfer and glacier hydrology were conducted by the J.N.U research group by Hasnain (1996), Hasnain and Thayyen (1999a,b). The interesting highlights are the occurrence of high sulphate content during the seasonal high discharges and glacially controlled sediment exhaustion is off set between July and mid-September by the impact of monsoonal regime on the supraglacial covered glaciers.

In the Pakistan Karakoram mountains the Snow and Ice Hydrology Project (SIHP) was conceived in 1981 as a collaborative programme of study of snow anf glacier hydrology in the upper Indus basin as a cooperative venture between IDRC, Canada and the Governament of Pakistan. Wilfrid Laurier university, Canada and Alpine Glacier Project of the University of Manchester, England were also involved were also involved in this project. Batura glacier basin was gauged to investigate climate-glacier-runoff relationship. Detailed measurement of temporal variations of suspended sediment flux in meltwaters draining the Batura glacier indicate an annual sediment yield of 6.0 kt km^{-2} $year^{-1}$ or 10.14 kt km^{-2} $year^{-1}$ was estimated from the glacier subsole assuming all sediment is derived from glacier erosion. Collins (1996) has estimated that 60 % of the annual sediment yield of the Hunza (4.7 kt km^{-2} $year^{-1}$) and more than 40 % of that of the Indus leaving the Karakoram (1.2 kt km^{-2} $year^{-1}$) are glacier-derived. Much sediment is deposited on the plain, reducing sediment delivery to the Arabian sea to about 200 kt km^{-2} $year^{-1}$.

The mass balance studies are present as snap shots and not as a time series Global Land-Ice Monitoring from Space (GLIMS) is an international project to ascertain the extent and conditions of the world's glaciers with accuracy and precision needeed for the accurate possible predictions for future change. GLIMS entails:

1. multispectral and stereo image acquisition of land-ice on an annual basis,
2. satellite imaging data to measure inter-annual image changes in glacier length, area, boundries and trnsient snowline. This will help to develop global baseline data against which subsequent glacier change can be assesed.

GLIMS will use primary data from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer, a Japanese instrument due for launch in June 1999 aborad NASA'S EOS AMI satellite.

NASA identified three Regional centres for the HKH region:

1. South Asia Regional Centre will be led by (Syed I. Hasnain). The south Asia RC as consisting of, to a first approximation, India, Nepal, and Bhutan. The boundry is the military line of control.
2. China RC is led by (Cheng Guodong/ Shiyin Liu) boundry with other Asian RC is concides with the line of control.
3. Southwest Asia RC is led by (Bishop/ Shroder) consists of Pakistan and Afghanistan.

The long-term objectives of each regional centre will be to perform data analysis. Each regional centre would perform, at a minimum, a standard analysis using a set of algorithms shared among all the centres. The important parameters to be analysed will be glacier ice extent, glacier ice motion, position of the transient snow line at the end of the melt season. The data products of the standard analysis will be relayed at the world Ice data centre in Boulder, Colorado USA. This data base would be freely available for general public use.

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